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NATIONAL BUREAU OF STANDARDS REPORT

6545

PROGRESS REPORT
ON
VENTILATION STUDIES AT LOCHRAVEN HOSPITAL
FOR THE PERIOD
(September 1, 1958 to June 30, 1959)

by

Carl W. Coblentz
Paul R. Achenbach
Edward F. Kramer

Report to

Department of Medicine and Surgery
Veterans Administration
Washington, D. C.

NBS

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NATIONAL BUREAU OF STANDARDS REPORT

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ON
VENTILATION STUDIES AT LOCHRAVEN HOSPITAL
FOR THE PERIOD
(September 1, 1958 to June 30, 1959)

by

C. W. Coblentz, P. R. Achenbach, E. F. Kramer
Air Conditioning, Heating, and Refrigeration Section
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to

Department of Medicine and Surgery
Veterans Administration
Washington, D. C.

IMPORTANT NOTICE

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(f) The effect of opening windows on the natural convection air exchange in individual rooms.

(g) The effect of wind velocity and direction on the ventilation of individual rooms and the wing as a unit.

It was planned that the helium tracer gas technique, thermocouple anemometers, and other apparatus for measuring air exchange and air velocity would be used in carrying out this investigation.

2. DESCRIPTION OF TEST SITE AND APPARATUS

Four rooms on the fourth floor of wing B in the Lochraven Hospital were used for most of the observations. The four rooms, No. 4-19, 4-20, 4-21, and 4-23, were in line on one side of the hall as indicated in Fig. 1. All four rooms had a northern exposure and were heated by steam convectors located under the windows. The heat output of the convectors was manually adjustable by a hand valve accessible to the occupant of the room. The occupants were free to open the windows as desired.

During the heating season, the fresh air for this ward was introduced at the end of the hall by means of a blower and thermostatically-controlled steam convector unit that was installed underneath the window. This convector is also indicated in Fig. 1. Since the patient rooms were equipped with manually-controlled steam-heated convectors, it was not possible to balance the temperature in these rooms with that in the hall during the test, when the doors of the rooms were closed.

The infiltration meter used for the tests consisted of twelve sensing probes and cables connected to a console containing the regulating and bridge circuits for measuring the relative helium concentrations at selected intervals. Each sensing probe consisted of an aluminum block with two identical cylindrical cavities containing matched thermistors. One cavity was hermetically sealed, the other ventilated by natural convection of the helium-air mixture in the room in which it was located. By incorporating the two heated thermistors in a bridge circuit, the thermal conductivity of the helium-laden air could be used to monitor the decreasing helium concentration in a room as a result of fresh air leakage.

LAYOUT OF TEST AREA

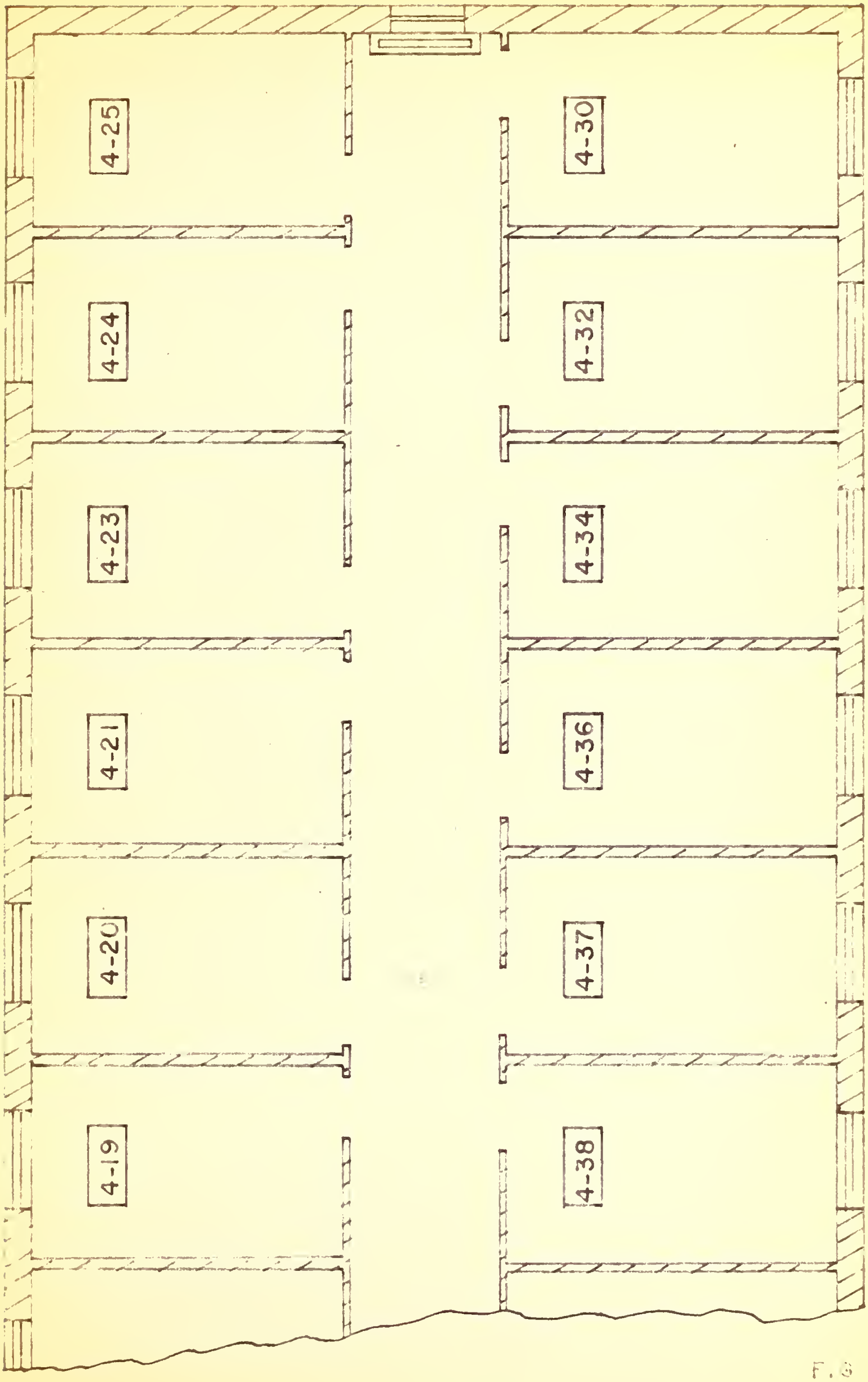


FIG. 1

The thermocouple anemometer used for air velocity measurements was designed and built by the National Bureau of Standards for directional measurements of low air velocity. It incorporated two pairs of hot and cold junctions heated by a small alternating current. Small diameter wire was used for two of the junctions and larger wire for the other two. Thus the small junctions were heated more by the alternating current than the larger ones, and a small thermoelectric emf was produced which could be related to the air velocity over the junctions by calibration. This type of instrument is especially sensitive at low air velocities in the range from 5 to 100 feet per minute.

The Lochraven Hospital contained a pilot ward consisting of 6 patient rooms and two lavatories separated from the main corridor of wing 4-B by an auxiliary corridor. Two doors connected the main and auxiliary corridors. This ward was occupied by patients with active tuberculosis and was used by the medical research staff for studies designed to show whether or not live tuberculosis organisms could be carried from the rooms through the ventilating system to the upper floor and produce tuberculosis infection in guinea pigs who breathed the air.

The ventilating system of the pilot ward consisted of a blower and duct system in a roof laboratory above the ward which recirculated large quantities of air through the pilot ward and diverted a smaller amount through the animal chambers before discharging it outdoors. In this system the fresh air supplied to the pilot ward equalled the amount diverted through the animal chambers. The windows of the pilot ward were carefully sealed with plastic sheeting and masking tape so the blower would produce a small negative pressure in the pilot ward relative to the main corridor. Several measurements of the ventilation rate in the pilot ward were made in 1956 using the tracer gas procedure.

Recently, a second animal chamber was installed in the roof laboratory to compare the rate of infection of the animals by the air from the pilot ward with and without germicidal lamps in the ducts supplying the animal chambers. A method for delivering equal volumes of air to the two chambers was required. The recirculating feature of the ventilating system was also blocked off and only the amount of air needed for fresh air makeup in the pilot ward was supplied to the animal chambers.

3. TEST PROCEDURES

3.1 Tracer Gas Techniques

In initiating the project, the first two months were used for building a new infiltration meter that was better adapted to this particular testing work than the model then on hand. It used aluminum for housing the sensing elements instead of brass, which was more pervious to helium gas, and was designed for a greater sensitivity to reduce the amount of helium required as a tracer gas. A complete recalibration was required due to the fact that the indicating meter used in the first model was no longer available from the factory and another kind of micro-ammeter had to be adapted to the new apparatus.

During the first visit to the hospital on October 22, 1958, it was found that the clearance between the doors and the floor was so small that the cables for the sensing probes could not be put through the closed doors between hall and patient rooms. A semi-permanent installation, therefore, was necessary and the cables were placed in the false ceiling of the halls and then through holes in the walls which led into the four patient rooms designated as the preliminary test area.

The first investigation to be made was the determination of the air exchange between these patient rooms and the hall. This was to be accomplished by introducing helium as a tracer gas into one or several of the rooms. Four rooms in the 4-B ward, Nos. 4-19, 4-20, 4-21 and 4-23, were equipped with 3 sensing probes each. The console was placed against the corridor wall between rooms 4-23 and 4-24. Three cables terminated in each of the four rooms about 3 ft above the floor; the probes were connected to these ends. The other ends of the cables were arranged to hang down through an opening in the false ceiling for connection to the console during the test; and to be stored above the false ceiling when not in use.

The temperature in the hall and in the rooms was determined with thermometers, at the outset. It was found that this was not satisfactory, however, and a series of 19 thermocouples was installed on the walls of the hall and of the four rooms with the junctions about 1 1/2 inches off the wall.

The method used for determining the air exchange between the patient rooms and the corridor, when the doors are open, was a modification of the tracer gas method as used for determining the air change rate of an enclosure. The air change rate of an enclosure is usually defined as the ratio of the hourly rate at which the air enters (or leaves) the enclosure to the volume of the enclosure.

The rate of change in concentration of a tracer gas caused by infiltrating outside air can be expressed by the formula:

$$-V\ (dc/dt) = Kc \tag{1}$$

where: V = volume of the enclosure

c = concentration of tracer gas at time t

K = average volume of air infiltration per unit time for the time interval

When $c = c_o$ at $t = 0$, the solution of the above equation is

$$c = c_o\ e^{-\ Kt/V} \tag{2}$$

or

$$Kt/V = \ln\ (c_o/c) \tag{3}$$

which indicates that the number of air changes occurring during the time t is equal to the natural logarithm of the ratio of the tracer gas concentrations at the beginning and at the end of this time interval.

3.2 Air Flow Measurements with an Anemometer

A series of tests was made to determine the air flow rates through the open door of one room by use of a thermocouple anemometer. These tests were made to confirm the results obtained with the tracer gas method, as there was some question whether or not opening of the doors for only two minutes would produce a higher air exchange rate between room and corridor than if the door was open continuously.

For this purpose the air velocity was measured at 6 inches and 18 inches below the top of the door and also the same distances from the floor. At the same time the direction of the air flow was determined with a smoke gun.

Similarly, the air flow through the doors of the first 12 rooms of the 4-B ward (see Fig. 1) and the flow from this wing toward the center of the building was measured using the thermocouple anemometer. This test was conducted at an outside temperature of 94°F with practically no wind. Almost all of the windows in the ward were open.

4. TEST RESULTS

The ventilation rates of rooms 4-19, 4-21, and 4-23 were observed a number of times between November 1958 and April 1959, for a total of 27 measurements under heating conditions. These measurements were made with the doors closed and with the doors open using the helium tracer gas technique. The temperature difference between the corridor and the room was observed in most cases. Table 1 summarizes the results of these tests.

Some correlation between ventilation rate and the temperature difference between the corridor and room can be seen in Table 1 when the doors were open, but there are a number of inconsistencies. It would be expected that the difference in air density caused by temperature difference would be the principal motive force for air exchange through the open doors, but outdoor wind velocity and direction probably had some effect. The measured air flow through the open doors ranged from 55 to 337 cfm per degree temperature difference with an average of 115 cfm per degree. The median value for air exchange through the open doors was 80 cfm per degree temperature difference.

The ventilation rate with closed doors ranged from 7 to 68 cfm with an average value of 23 cfm for all the tests. The ventilation rate with closed doors would be more closely related to the outdoor temperature, wind velocity and direction, and to the tightness of window closure.

Table 1 indicates that the higher values of ventilation with doors closed, occurred when the wind was from the southeast or southwest which would tend to increase the static pressure at the outdoor air intake of the steam convector in the hall.

Table 1

Ventilation of Rooms in Ward 4-B

Date of Test	Room No.	Temp Diff**	Ventilation (CFM) Doors Open	Ventilation (CFM) Doors Closed	Outside Temp °F	Prevailing Wind Direction	Wind Velocity MPH
11/5/58	23	-	400	18	68	S	10
11/17/58	23	3*	236	56	54	SE	7
	21	2*	183	46	54	SE	7
11/24/58	21	2*	131	31	70	SW	18
12/2/58	21	1 1/2*	240	7	42	NW	9
	19	1 1/2*	288	16	42	NW	9
12/3/58	21	2*	138	11	40	ENE	9
	19	2*	130	32	40	ENE	9
12/17/58	23	1 1/2*	148	21	41	WSW	11
	21	-*	372	10	41	WSW	11
1/6/59	23	4*	317	11	26	NW	23
	19	3*	165	12	26	NW	23
1/7/59	23	-	102	11	28	W	17
	19	-	363	14	28	W	17
	23	-	160	12	33	WNW	11
	19	-	392	12	33	WNW	11
1/21/59	23	2.7	175	11	62	SSW	17
1/27/59	23	3.5	358	10	31	WNW	2
	21	5.0	381	13	31	WNW	2
4/10/59	23	1.5	191	18	59	ENE	17
	21	.4	134	26	59	ENE	17
4/14/59	23	4.2	315	18	54	NNW	21
	21	4.2	269	31	54	NNW	21
4/21/59	23	4.2	364	30	56	ENE	8
	21	5.7	457	25	56	ENE	8
4/28/59	23	1.2	268	68	48	SE	15
	21	1.5	110	58	48	SE	15

* Temperatures observed with thermometers
** Temperature difference between room and corridor at 5 ft level

Thus the average air change rate in the rooms with the doors closed, which was probably not all fresh air from outdoors, was about one per hour, whereas the average air change rate between corridor and each room with the doors open was about six per hour in terms of the room volume.

During winter conditions, the air delivery of the steam convector unit at the end of the hall was 1080 cfm with the air filters clean. One measurement made with the filters dirty indicated an air delivery for the convector unit of only 375 cfm of which about 100 cfm was recirculated air.

Fig. 2 is an illustration of the method of evaluating the test data when using the tracer gas technique. Referring to equation (3) cited in the Test Procedure, it is seen that the logarithm of the ratio of the initial and final helium concentration will be a constant if the rate of fresh air leakage is a constant, that is, if the forces producing air leakage remain steady. Thus the value of the concentration of helium plotted against time on semi-logarithmic paper would be a straight line. In Fig. 2, the rate of air leakage with the doors closed can be determined from the slope of the straight line through the plotted points for the period from 0 to 20 minutes. The break in the line shown at 20 minutes was caused by an arbitrary change in amplification of the bridge circuit signal, but the slope of the decay curve remained constant as long as the doors remained closed.

The doors were opened for 2 minutes at 25 minutes after the start of the test. About 7 minutes were required after closing the door to re-establish a well-mixed condition in the room between the helium-laden air and the air entering from the corridor, after which the decay curve returned to the same slope as before the doors were opened. The change in concentration caused by opening the door can be evaluated by the distance separating the center and right hand portions of the decay curve at constant slope. For the test, illustrated in Fig. 2, the ventilation rate with the door closed was 31 cfm and with the door open was 216 cfm.

When measuring the air flow through an open door with the thermocouple anemometer, it was found that the velocity fluctuated considerably and even changed direction sometimes during a single set of observations. It was necessary, therefore, to take the average of a number of observations to obtain useful values. When the magnitude and direction of the air flow was plotted against

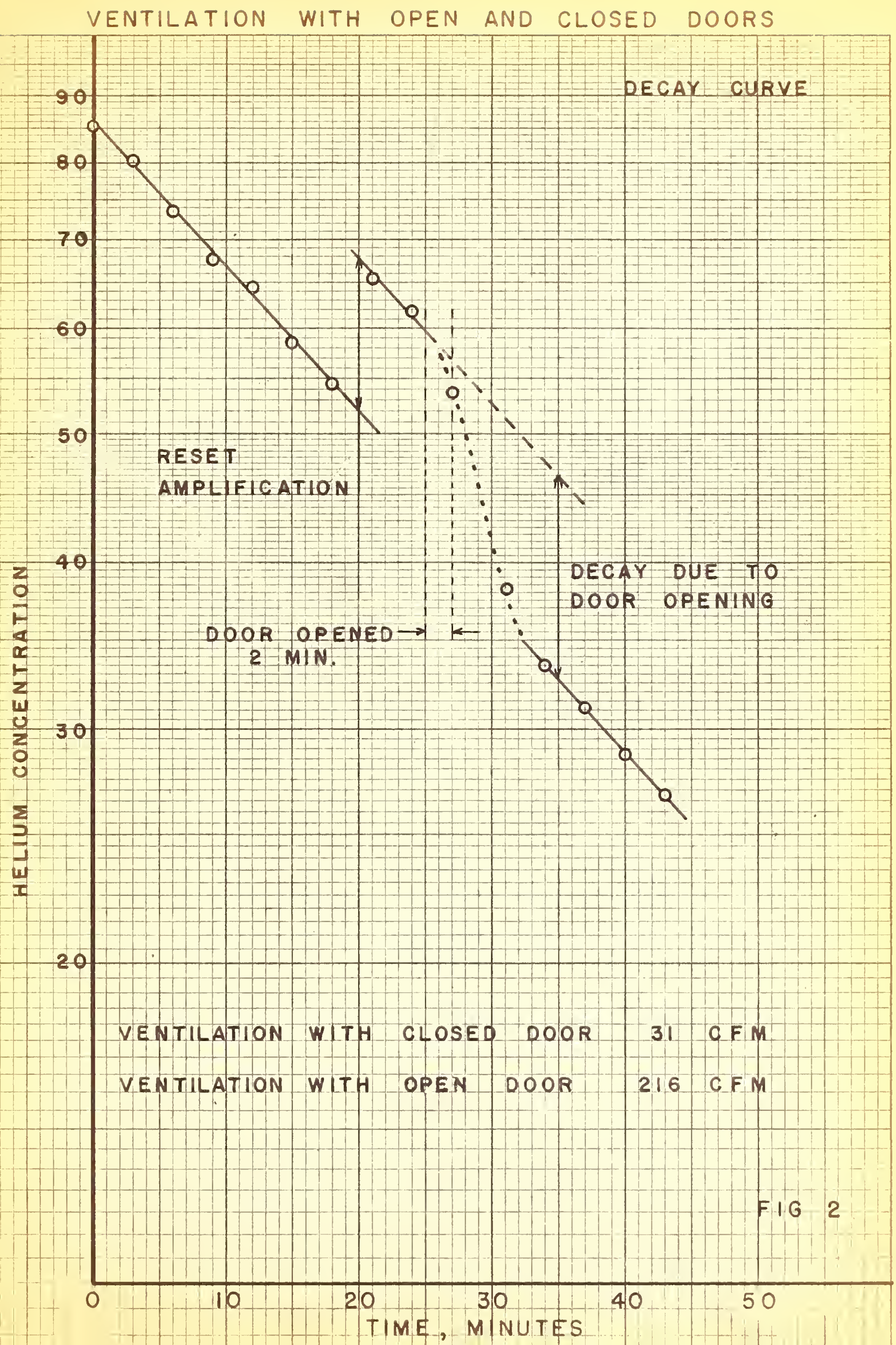

VENTILATION WITH OPEN AND CLOSED DOORS
DECAY CURVE
90
80
70
60
50
40
30
20
RESET AMPLIFICATION
DOOR OPENED 2 MIN.
DECAY DUE TO DOOR OPENING
HELIUM CONCENTRATION
VENTILATION WITH CLOSED DOOR 31 CFM
VENTILATION WITH OPEN DOOR 216 CFM
0
10
20
30
40
50
TIME, MINUTES

FIG 2

height above the floor, it was found that the velocity pattern was approximately a straight line with a neutral zone somewhat above the center of the door opening at which there was a negligible air motion. This pattern is illustrated in Fig. 3 which represents the average results of nine tests in room 4-23 with a temperature difference of 1.3°F between room and corridor.

The height of the door was 83 inches and the width 42 inches. Based on the indicated velocity pattern in Fig. 3, the neutral zone was about 50 inches above the floor for these conditions. The indicated air flow from the room to the hall would be

$$\frac{42 \times 50 \times 13.3}{2 \times 144} = 97 \text{ cfm} \qquad \text{and}$$

the flow from hall to room would be $\frac{42 \times 33 \times 8.75}{2 \times 144} = 42$ cfm

corresponding to a net exchange of 55 cfm. The direction of air flow in the upper and lower parts of the doorway would depend on the relative temperature levels in the two spaces. The difference between the inward and outward flow through the connecting door would be equal to the window leakage, if the remainder of the room was airtight. The following table shows the results obtained with this method during several sets of observations.

Table 2

Air Flow Measurements Through Door
(Determined with an Anemometer)

Temp. Diff. °F	Air Flow Rate, cfm into room	from room	No. of Tests
1.3	42	97	9
3.2	67	455	7
3.3	48	509	15

AIR FLOW THROUGH OPEN DOOR

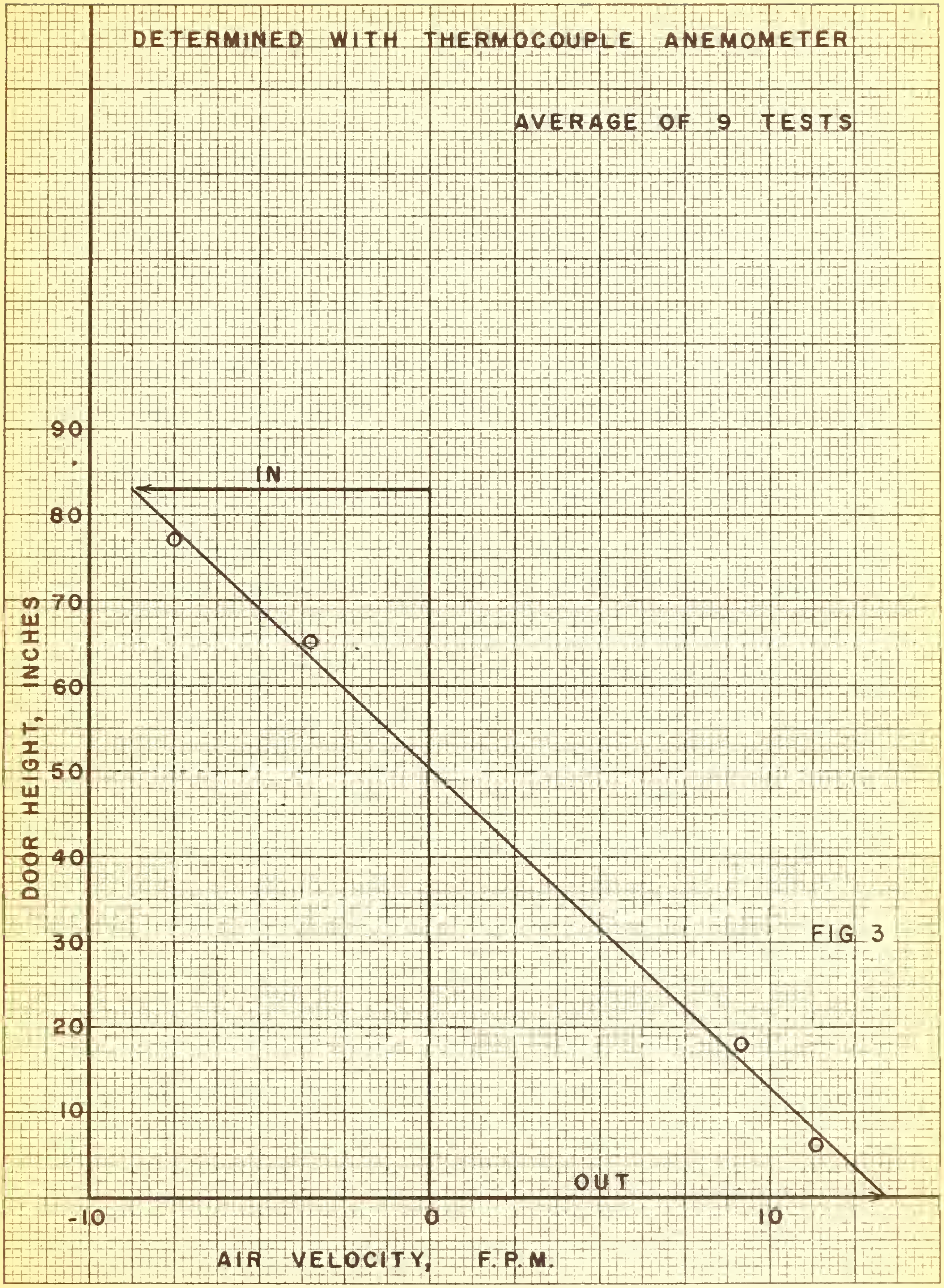


FIG 3

Similarly, the air flow through the doors of the first 12 rooms in Ward 4-B and the flow in the corridor from this wing toward the center of the building was measured when the outdoor temperature was about 94°F. There was practically no wind and the windows in most of the patient rooms were open. The air velocities were not steady at any point and, at times, the flow changed direction at a given station, so the measurements only indicate the order of magnitude of the air exchanges.

The net air flow rate through the windows in the patient rooms was computed as the difference between the inward and outward flow to the room at the hall door. The air movement toward the corridor and from the corridor at each of the 12 door openings is shown in Table 3. Fig. 7 shows a floor plan of the test area in which the values of Table 3 and also the air flow rates determined in the corridor are marked as arrows with the respective flow rates in cfm. In many cases, there was one-way flow only at the door, but in a few cases there was two-way flow. In 6 of the 12 rooms there was flow only from the room to the corridor, in amounts ranging from 317 to 2380 cfm, whereas the air flow was entirely from corridor to room in 3 other cases, in amounts ranging from 195 to 1463 cfm. The net air movement toward the corridor for the twelve rooms was 5373 cfm and an additional 2835 cfm was recirculated between rooms and corridor. The total air exchange between corridor and rooms represented about 81 air changes per hour with respect to the corridor volume. There was undoubtedly more fresh air exchange through the windows in the patient rooms, in most cases, than is indicated by the net air exchange at the doors in Table 3, because there were movable frames at three heights in each window. This would provide a ready means for two-way air flow at the windows under the influence of stack effect in the rooms.

In addition to the net flow of 5373 cfm from the 12 rooms toward the hall, an additional 2449 cfm entered the corridor through the window at the end of the hall indicating a total rate of air movement of 7822 cfm toward the center of the building. Measurements of the air flow in the corridor toward the center of the building at a distance of 72 ft from the end, indicated a flow rate of 6926 cfm toward the center of the building of which 606 cfm was flowing through the space above the false ceiling in the corridor. Thus a discrepancy of about 900 cfm is indicated between the air movement in the corridor toward the center of the building as measured 72 ft from the end and the sum of the net air movement through the

Table 3

Room Number	Air Flow through Doors in Patient Rooms, cfm		
	To Corridor	From Corridor	Net Air Exchange
19	317	0	317
20	453	0	453
21	0	195	195
23	0	806	806
24	47	57	10
25	1536	0	1536
30	0	1463	1463
32	2380	0	2380
34	1684	0	1684
36	1028	129	899
37	324	185	139
38	439	0	439

room doors and that entering the window at the end of the hall. This difference is not unexpected considering the fluctuations observed during the measurements.

It had been planned that the air movement from one patient room to the adjacent one by way of the corridor would be measured during the series of tracer gas studies summarized in Table 1. Only in two of the fourteen tests was a trace of helium detected in the next room when the doors were closed after the 2-minute opening period. Since a flow of about 60 cu ft of air (helium-contaminated) from one room to the next room would have produced a measurable deflection on the indicating meter of the instrument in the second room, it appears that this air flow rarely reached a rate of 30 cfm.

This conclusion was corroborated by the measurements of the air velocities in the door areas by means of an anemometer. It was found that on the same side of the corridor the air movement from corridor to rooms was always either through the lower or through the upper part of the doors, depending on whether the hall or the rooms were warmer and upon the direction of the wind. If helium-contaminated air left one room through the upper portion of its door and air moved into the next room through the lower part of its door, it appears likely that only through very considerable turbulence in the corridor would it be possible for a significant amount of air to flow from one room into the adjacent one. Only if the temperature gradient between the two rooms and the corridor was opposite in direction could a considerable air movement from one room to the next one be expected. This was the case in one of the two instances when helium was detected in the next room.

5. VENTILATION OF THE PILOT WARD

In order to evaluate the infectivity of the air from the pilot ward when circulated through the animal chambers, the air change rate of the ward had to be kept constant. The ventilation rate should be set at the minimum required for the needs of the patients in the pilot ward. A ventilation rate of 30 cfm per patient, that is, a total ventilation rate of 180 cfm was selected.

The large Trane ventilating blower which had been used for recirculation of large quantities of air to the pilot ward was by-passed and a new blower, ILG type PE-4 rated at 195 cfm with

2 3/4 in. W.G. pressure drop, was installed. An orifice plate, of a size calculated to produce about 1 in. W.G. pressure drop, was provided in each of the 10 in. diameter ducts to the animal chambers. This arrangement was intended to produce equal flows of air to both animal chambers even when one of them was open for servicing. Several tests of the ventilation of the pilot ward were made with this arrangement which led to the detection of a leak in one of the window seals. In order to reduce the transmission of blower noise into the ward through the duct system, a 5-ft length of sound-absorbing duct was installed, and the blower was mounted on an elastic pad.

The ventilation rate determined in the pilot ward by means of the helium decay method was 0.886 air changes per hour. Since the total volume of the ward was 11,320 cu ft, this corresponded to a rate of 167 cfm. This flow rate was corroborated by the manufacturer's flow-pressure curve for the pressure observed across the blower. This curve indicated an air flow rate of 176 cfm for the observed pressure drop of 3.00 in. W.G. across the blower; which was 9 cfm, or 5 percent, higher than the value determined with the helium decay method. This agreement was considered satisfactory. It also indicated that all of the air that passed through the blower had come from the pilot ward, a fact which could not be determined otherwise, since the ducts were so enclosed in the ceiling that a visual inspection of their tightness was not possible.

When the decay rate of E coli bacteria passing with the air stream through the blower was determined by the medical research staff at Lochraven Hospital, it was found that the rate was excessive and was impeding the bacteriological test procedure. The high speed of the blower (3400 rpm) was considered a possible cause of the destruction of the bacteria. It was, therefore, decided to return to the original large blower system which could be reconnected to the ducts without too much alteration. The discharge pressure of this blower at its operating speed of 212 rpm was determined to be 0.07 in. W.G. with the discharge blocked. The ventilation of the pilot ward was measured by the helium decay method with the blower operating at this speed. Two tests were conducted on one day which indicated ventilation rates of 263 cfm and 280 cfm, respectively. This ventilation rate was higher than desired, and the variation of 17 cfm between the two values was thought to have been caused by the small pressure drop in the ventilating system and the changes in the outside temperature between the morning and afternoon test.

An attempt was made to stabilize the flow rate by introducing a flow resistance in the system. The orifice plates in the 10 in. duct were increased to 7 1/2 inches in diameter which was calculated to produce a pressure drop of approximately 0.01 in. W.G. at an air flow rate of 120 cfm in the duct to each animal chamber. This flow resistance was introduced to reduce the air flow through the blower, somewhat, and also to assist in stabilizing the flow rate. Three tests made under this condition indicated flow rates (ventilation of the pilot ward) of 217 cfm, 232 cfm and 233 cfm, respectively.

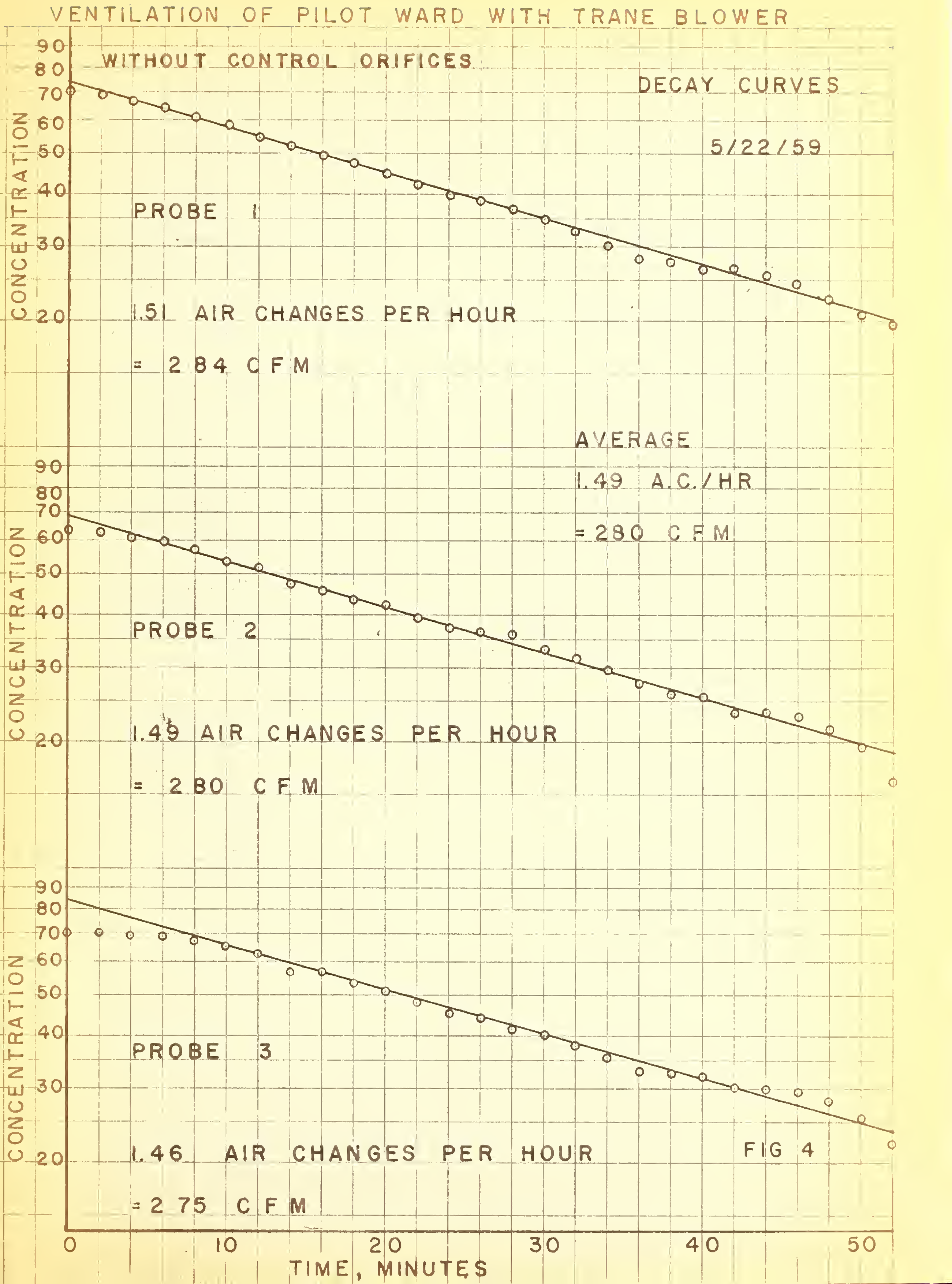
The decay measurements originally conducted inside the pilot ward represented too great a hazzard for the test personnel who had to spend about 5 hours in the ward. Therefore, the installation of the instrumentation was discontinued in the ward and it was moved up to the roof laboratory where several probes were placed in the ventilating duct from the ward. Fig. 4 and Fig. 5 show graphs of the observed concentration rates. It will be noted that the plotted observations in Fig. 4, which was conducted inside the pilot ward, fall much closer to the straight line on semi-logarithmic paper than those of Fig. 5 which were determined from the roof laboratory. The cause of the fluctuating decay rate in this study could be due to inadequate mixing of the helium in the ward since the deviations from the straight line coincide on all three probes.

6. DISCUSSION AND CONCLUSIONS

The average air exchange rates observed during the heating season in the four test rooms of Ward 4-B are shown diagrammatically on the floor plan in Fig. 6 for a selected group of tests. By making certain assumptions, the concentration of a contaminant or contagion in any one of the rooms or at any station in the corridor under steady state conditions can be computed for selected rates of generation of contagion in each room and ventilation with fresh air. The following assumptions were made for the present analysis:

(a) the air exchange rate through each of the windows was equal to the average value observed for four of the rooms,

(b) the air exchange rate between each room and the corridor was equal to the average value observed for the four test rooms,



VENTILATION OF PILOT WARD WITH TRANE BLOWER
WITHOUT CONTROL ORIFICES
DECAY CURVES
5/22/59
CONCENTRATION
90
80
70
60
50
40
30
20
PROBE 1
1.51 AIR CHANGES PER HOUR
= 2 84 CFM
AVERAGE
1.49 A.C./HR
= 280 CFM
PROBE 2
1.49 AIR CHANGES PER HOUR
= 2 80 CFM
PROBE 3
1.46 AIR CHANGES PER HOUR
= 2 75 CFM
0
10
20
30
40
50
TIME, MINUTES

FIG 4

VENTILATION PATTERN UNDER HEATING CONDITIONS

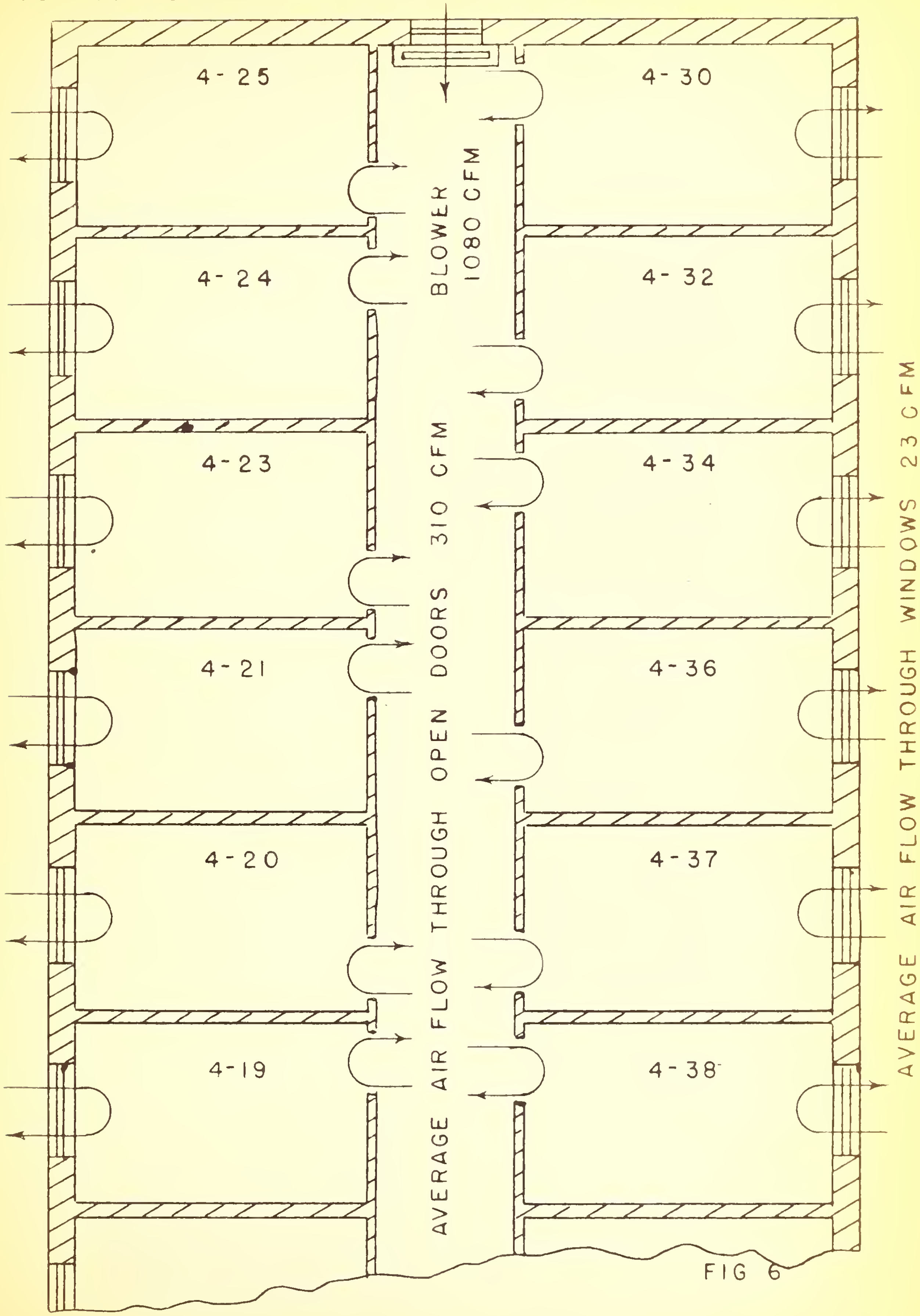


FIG 6

(c) the fresh air supply rate through the hall convector was equal to that measured when the filter in the convector was clean,

(d) the fresh air entering the windows left each room by way of the door to the corridor,

(e) the air entering the rooms through the windows and doors was thoroughly mixed with the room air,

(f) the air exchanged between corridor and rooms was thoroughly mixed with the corridor air, downstream from the door opening, and

(g) one unit per minute of contagion or tracer gas was introduced into each room.

The values for the concentration of contagion or tracer gas in units per thousand cubic feet of air in a ward with ten rooms located symmetrically on each side of the corridor for the conditions assumed above are summarized in Table 4. Under steady state conditions these concentrations would be independent of the size of the rooms and corridor sections, and depend only on the magnitudes of the air exchange rates.

Table 4

Concentration of Contaminant Along The Corridor and In The Rooms of A Hospital Ward
(Under ventilating conditions shown in Fig. 6)

Order of Location of Room Pairs on each Side of Corridor	Concentration of Contaminant units per 1000 cu ft	
	Room	Corridor
1	3.00	1.78
2	4.66	3.40
3	6.17	4.92
4	7.58	6.33
5	8.90	7.64
6	10.10	8.84
7	11.22	9.97
8	12.27	11.03
9	13.25	12.05
10	14.20	12.98

The equations used to determine the concentrations shown in Table 4 are:

$$C_{r_m} = \frac{C_{c(m-1)} Q_c + b}{Q_c + Q_r}$$

$$C_{c_m} = \frac{2mb}{Q_h + 2m\, Q_r}$$

where:

m = the number of the symmetrically-placed pair of rooms on either side of the corridor numbered from the end of the corridor

Q_r = rate of fresh air entry at each room window, cfm

Q_c = rate of air exchange between corridor and each room, cfm

Q_h = rate of fresh air entry through hall convector, cfm

b = number of units of contagion or tracer gas per minute released in each room

C_{r_m} = concentration of contaminant in rooms m

C_{c_m} = concentration of contaminant in corridor space between rooms m and m + 1.

It will be noted that the concentration in the first pair of rooms, which exchanged uncontaminated air with the corridor, was only 21 percent of that in the tenth pair under steady state conditions and 23 percent of the concentration in the corridor just after the tenth room door. The corridor concentration outside a given room door ranged from a minimum percentage of 59.3 of the concentration in the corresponding room for room 1 to a maximum percentage of 91.4 for room 10. The concentrations in the various rooms and parts of the corridor would be changed somewhat, if the

hospital wing were pressurized so the flow of air through the window cracks was outward instead of inward as assumed for this analysis.

Since the air leakages through all of the windows and the air exchanges through all of the hall doors were not equal, there would be variations from the values of concentration summarized in Table 4. Also, imperfect mixing of the air in the corridor might cause the concentration of contaminant to be higher near the ceiling than near the floor, or vice versa, depending on the relative temperature levels in the corridor and rooms. However, the analysis of the winter time ventilation pattern illustrated in Fig. 6 reveals two important conclusions; first, that the high air exchange rate through the doors to the corridor causes the concentration of contaminants in the corridor to approximate that in the rooms and; second, the concentration of contaminants increases many fold from the fresh air inlet to the points of air exhaust toward the center of the building.

Figure 7 shows diagrammatically the air exchanges that occurred through the doors between the various patient rooms and the corridor during a hot summer day when the outdoor temperature was about 94°F, with practically no wind, and with most of the windows open. In this figure the flow of air through the windows is shown as equal to the net exchange through the corresponding door. Actually, more fresh air could have moved through the windows than is indicated because there were three movable frames in each window at different levels. The air flow vectors in Fig. 7 indicate a rather free exchange of air between spaces and reveals no simple pattern. For purpose of analysis it was assumed that the air exchange was so unrestricted that the twelve rooms could be considered as one large room with 12 units of contaminant and a total of 10,350 cu ft of fresh air introduced per minute. Under steady state conditions, this would correspond to an average concentration of 1.16 units of contaminant per thousand cubic feet of air for the whole space. This value is about one third that computed for the first pair of rooms under winter conditions. Undoubtedly, the average and local concentrations would vary considerably with the wind during summer conditions when the windows were open.

The data in Table 4 and Fig. 6 show that the high rate of air exchange between patient rooms and the corridor cause the concentration of air-borne contaminants to be nearly as high in the corridor as in the adjoining rooms during winter conditions. The contaminants in the corridor would be carried toward the main part of the

VENTILATION PATTERN UNDER SUMMER CONDITIONS

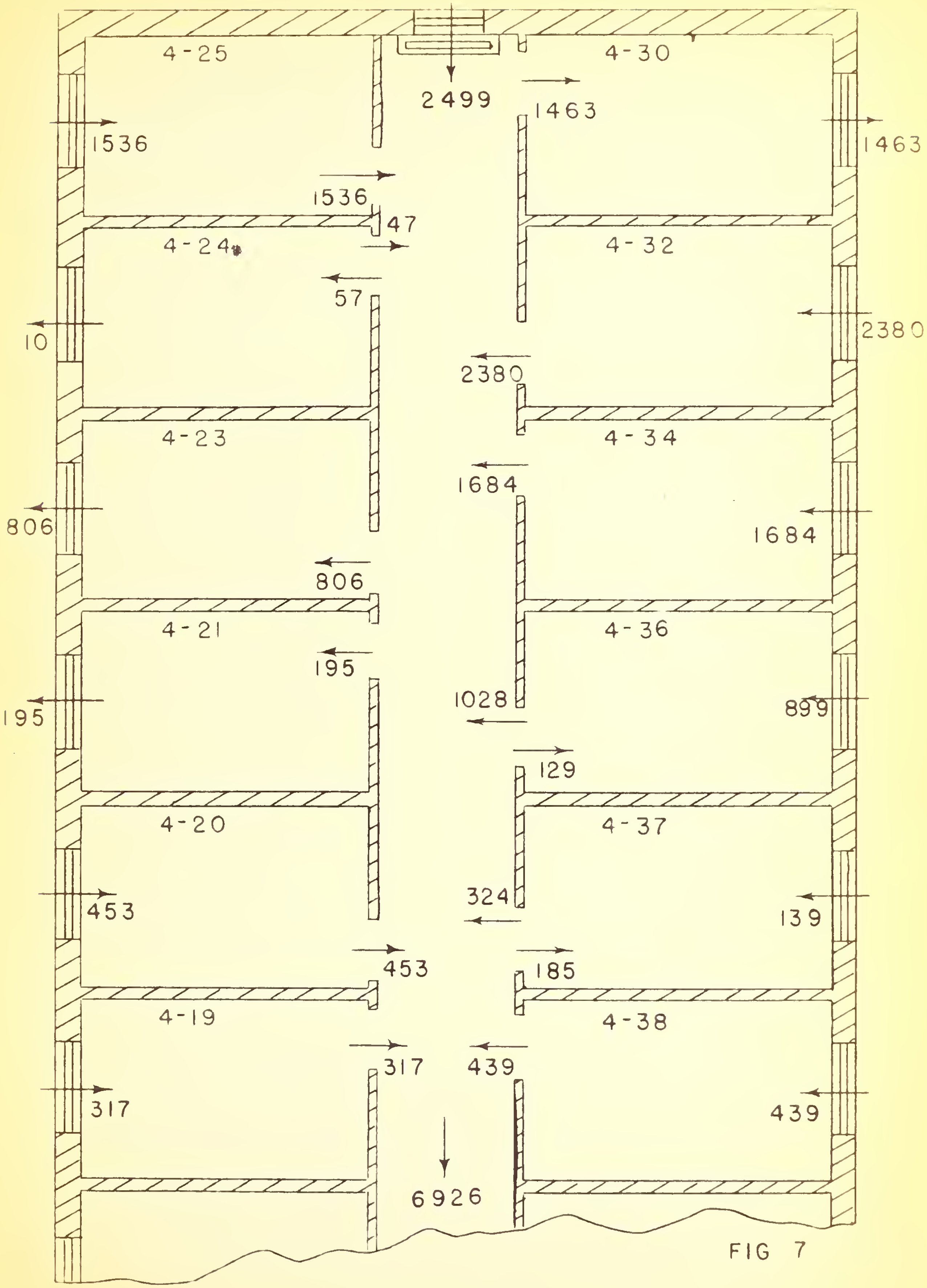


FIG 7

hospital to the several air exhaust openings in service rooms, etc. Reduction of the concentration in the corridors or in the corridors and patient rooms could be accomplished in three ways, (1) by dilution with fresh air, (2) by isolating the contaminants in the patient rooms where they originate, or (3) by using germicidal means in the corridors or in the rooms or both to destroy the contaminants.

The dilution method has been widely used in tuberculosis hospitals in the past. The possibilities of dilution with fresh air are illustrated, in principle, by the earlier analysis of the winter and summer air exchanges, shown in Fig. 6 and Fig. 7. However, very large quantities of heat would be needed to warm the necessary fresh air during winter conditions and, if comfort were desired in the summer time, very large air conditioning equipment would be required.

The contamination in the corridors could be materially reduced, if not eliminated, by keeping the doors to the patient rooms closed, except during entry, and maintaining a slight positive pressure in the corridor. However, this would cause the level of contamination in the patient rooms to rise significantly unless the air exchange through the windows was increased by a factor of ten or more which would again significantly increase the heat requirements. If the window leakage was not increased the nurses and hospital staff would be subjected to the higher concentration of contamination for the periods of time they spent in the patients' rooms.

High efficiency air filters, ultraviolet radiation, glycol vaporizers, and lithium chloride brine dehumidifiers have all been used to reduce the pathogenic microorganisms in an air stream either by killing them or filtering them out of the air. The relative merit of these different types of equipment has not been established. However, a proposed pilot installation of germicidal lamps was discussed with the research medical staff at the Lochraven Hospital that would coordinate the germicidal function of the lamps with the observed pattern of air movement between the patient rooms and corridor in Ward 4-B. This arrangement involved placing the lamps above a grating in the corridor over the doorway and opposite an opening in the wall of the room over the doorway in a location that would irradiate all of the air passing through the doorway and also direct ultraviolet radiation into the room in the zone between eye level and the ceiling. A grating in

the opening over the doorway prevented seeing the source of radiation from anywhere in the room and the overhead grating in the corridor prevented seeing the source of radiation, except from directly beneath the lamp. Air exchanged between the patient rooms and corridor would pass through the radiation zone whether the room was cooler or warmer than the corridor.

This proposal was further developed by the research staff at the hospital and a pilot installation is being made in Wing 4-B to determine the effectiveness of the system in controlling the spread of living microorganisms. When the installation is completed, further measurements of the air flow patterns over the germicidal lamps and in the patient rooms will be made.

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